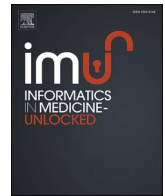ELSEVIER

Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Impact of meteorological parameters on COVID-19 pandemic: A comprehensive study from Saudi Arabia

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ABSTRACT

Background: The Coronavirus disease 2019 (COVID-19) has now been declared a global public health disaster with no currently available vaccine. This study was undertaken to analyse the effect of meteorological parameters such as temperature, humidity, and wind speed on the spread of ongoing COVID-19 in Saudi Arabia.
Methods: The COVID-19 dashboard for five major cities of Saudi Arabia - Riyadh, Makah, Jeddah, Medina and Dammam was used for data collection. The data on weather were collected from the Weather Underground Company (IBM business GA, USA, 2020). The data were analysed by Spearman's rank correlations using JASP statistical software in two main sections. In the first section the data on COVID-19 from cities were combined to analyse the overall picture of COVID-19 and in the second section, different meteorological parameters such as temperature, humidity and wind speed were analysed.
Results: Novel data revealed interesting facts on the spreading of COVID-19 in Saudi Arabia, the data showed that the number of COVID-19 positive cases increases due to the decrease of temperature or humidity, whereas an average decrease in the wind speed was also found to be associated with an elevation of the number of positive cases.
Conclusions: This study determined the impact meteorological factors on the infectivity rate of COVID-19. An inverse association was found between the meteorological parameters with the spreading of COIVD-19. Therefore, this study directs the health authorities to implement specific measures against the spreading of this global pandemic based on weather patterns.

1. Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) belongs to the family of enveloped RNA virus that is accountable for causing an infection termed as coronavirus disease 2019 (COVID-19) among humans and has taken the form of a pandemic within a brief period of a few months [1]. The first case of COVID-19 was initially reported in December 2019 from a city named Wuhan, which is the capital of Hubei province situated in the People's Republic of China [2]. World health organization affirmed SARS-CoV-2 as a Public Health Emergency of International Concern on Jan 30, 2020, and later, on Mar 11, 2020, it was categorized as a pandemic [3]. SARS-CoV-2 is a zoonotic virus, but the exact zoonotic source for this virus is not yet confirmed. Human infections from various members of the Coronavirus family are not novel, as previously six viruses related to this family were accountable for causing infections among humans. SARS-CoV-2 is labelled as the seventh member of the coronavirus family that has infected humans after the Middle East respiratory Coronavirus (MERS-CoV) [4]. The COVID-19 pandemic spread globally, affecting nearly all countries around the globe and infecting 22, 536, 278 people, and 789, 197 numbers of confirmed deaths have been reported by WHO to August 21, 2020 [5]. This now has been declared a global public health disaster

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[6]. The first case reported in the Kingdom of Saudi Arabia (KSA) was on March 2, 2020, in Qattif city situated in the eastern province of KSA and other cases were reported from other regions as well, and until August 21, 2020, 303,973 was the number of confirmed cases that have been identified, out of which the number of the deaths is 3548 [5–8]. In order to confront the spreading pandemic, various preventive strategies were implemented across the globe. Like other countries, KSA also commenced various preventive measures to slow down the spread of this viral infection, including practicing of social distancing, wearing masks, creating awareness of the use of digital technology, screening programs, a countrywide lockdown, appointment of new medical staff, and use of artificial intelligence technologies for contacting or tracing of infected people, and planning then to quarantine [6–8]. As the mode of spread of this virus is mainly via droplets from an infected person to others which can spread to a distance of about 3–6 feet, the elementary measure in controlling the spread was to implement travel restriction between countries as well as different regions of the same country. Keeping this under consideration, the government of KSA placed a travel ban on residents of one city to move to other cities under normal circumstances; this measure played a significant role in controlling the spread of this infection from region to region, as well as assisting in providing an accurate count of the number of cases in each city/region, which helped in detecting infective persons and taking the appropriate protective measures such as quarantine and wearing masks that helps in the overall management of this disease [7,8]. Furthermore, the diagnosis of this viral infection in its early phase plays a vital role to handle this novel infection. There are a number of diagnostic techniques available, but WHO recommended the use of real-time reverse transcription-polymerase chain reaction (rRT-PCR) since January 17, 2020 [5,9] and now the Loop-mediated isothermal amplification (LAMP) techniques are also in use for testing of COVID-19 patients [10]. In addition to these, radiographs of lungs and histopathology of lung biopsies have also been currently in use for the diagnosis of this novel infection [11,12].

Recent studies conducted on COVID-19 revealed that various environmental factors, particularly the climate, also have a contribution to the mode of transmission of SARS-Cov-2 [13]. A range of epidemiological studies has shown a significant association between the meteorological parameters with the survival period and the spread of this virus among the community [13,14]. This information is vital as the meteorological parameters vary from region to region; hence understanding the effect of climate can be beneficial to limit the spread of this virus. Various studies proved that cold temperature provides a favorable environment for incubation and virulence of this virus, which aids in its efficiency to potentially infect humans [15]. Chin et al. studied the effect of temperature on the survival rate of SARS-CoV-2 and came with the finding that it is a heat-sensitive virus and is stable at 4 °C whereas when the temperature was rose to 70 °C the incubation period of this virus significantly lessen to 5 min [16]. Another study conducted in China to test the effect of temperature on the infectivity rate of this virus revealed that when the temperature was below 3 °C, the number of COVID-19 cases were amplified [17]. Considering these studies under appraisal, it is crucial to conduct a study in order to analyse the association between the meteorological parameters and the COVID-19 pandemic. As the climate in KSA varies from region to region so in our study, we have studied the effect of meteorological parameters on the infectivity rate of COVID-19 by analyzing a day to day data of a number of positive cases from different cities of KSA hence providing detailed insight about the association of infectivity rate of SARS-COV-2 virus under diverse weather conditions in order to provide valuable information for policymakers and community.

2. Materials and methods

2.1. Data collection

The data on infectivity of COVID-19 in Saudi Arabia were collected from COVID-19 Dashboard [18]. The data on the total number of cumulative cases of COVID-19 from the top five cities in KSA - Riyadh, Makah, Jeddah, Medina and Dammam were collected from the Ministry of Health, Saudi Arabia and The General Authority for Statistics of Saudi Arabia, 2010 [18,19]. Only suspected cases of COVID-19 infection were diagnosed as per instructions by the Saudi health ministry authorities, but the diagnosis was compulsory for all medical staff including doctors, nurses and technicians [18]. Riyadh is the capital of KSA and has the highest population, which is nearly 5236901; it has a dry climate with the maximum temperature reaching up to 47 °C in summer and minimum temperature recorded up to −1 °C in winters. Jeddah city is a coastal city and is located adjacent to the red sea; it has a hot and humid climate. Dammam is situated in the eastern province about 20 km from Qateef city, where the first case of COVID-19 was diagnosed; it has a warm, very humid climate as it is adjacent to the Arabian Gulf. Medina and Mecca have significant importance as they are considered as two holy cities for Muslims. So they have a massive influx of pilgrims throughout the year. In the year 2019, about 2.4 million pilgrims visited Mecca and Medina to attend the religious ritual [18,19]. These statistics can contribute to assessing the anthropometric spread of COVID-19 cases across different regions in KSA.

2.2. Weather data

The weather data were obtained from the Weather Underground website https://www.wunderground.com, which rely on local weather stations for meteorological information [20]. Historical data were retrieved for five major cities (the capital Riyadh, Makah, Jeddah, Medina, and Dammam) in Saudi Arabia. Data include maximum and average daily temperature in Celsius (°C), maximum and average dew point (°C), maximum and average relative humidity (%), maximum and average wind speed in miles per hour (mph) and average atmospheric pressure in mm of Mercury (Hg). Dew point is the temperature that varies according to pressure and humidity, below which water droplets begin to condense and form dew. It indicates the level of humidity in the air, so the higher dew point means a higher level of humidity. The data for the average wind speed for different cities was important as SARS-CoV-2 is transmitted via respiratory secretions when an infected person coughs or sneezes, the virus is released in the air in the form of droplets, and probably speed of wind can contribute in the dispersal of this virus in the surrounding area.

2.3. Data analysis

We used JASP statistical software (Version 0.12.2) for the statistical analysis and producing figures, including the scatter plots [21]. It is an open-source computer program available for free use. Spearman's rank correlation test was used to check the correlation between the numerical variables. Correlation coefficients are provided with 95% confidence intervals. A P-value of <0.05 considered a statistically significant relationship. The analysis is divided into two main parts. The first part combines data of all five cities in one analysis, which gives an overall picture of the effect of weather on COVID-19 in Saudi Arabia. As the weather differs from city to city, we include a separate second part of analysis for each city for more detailed information, easier and more appropriate comparison.

3. Results

3.1. Distribution of COVID-19 infected cases

This study was conducted to investigate an association of weather or atmospheric parameters on the spread of COVID-19 infection among five major cities of the Kingdom of Saudi Arabia - Riyadh, Makah, Jeddah, Medina and Dammam. The distribution of total COVID-19 confirmed cases in these cities of Saudi Arabia are summarized in Table 1. Our results revealed that the highest number of positive cases was 24,957 reported from Riyadh city which has a population of 523690l. Mecca city with a population of 1,684,408 was reported 17,616 infected cases. Jeddah city has population of 3,457,794 and it ranks at third position with 17,215 positive cases. Medina and Dammam city stood on fourth and fifth position with 10,368 and 6429 number of positive cases reported respectively. The number of deaths due to COVID-19 infection was highest in Mecca city followed by Jeddah and Medina with a number of 278, 247 and 60 respectively. In Riyadh where the highest number of positive cases were reported the number of deaths was 47 which is low in comparison to cities where less number of positive cases were reported in our study while Dammam city reported only 24 deaths which is the least number of deaths due to COVID-19 in our study. The trend of COVID-19 patients in KSA was analysed from March 5, 2020 to May 20, 2020. The results showed that the active cases during this time continuously increased but the curve for new cases become same after May 20, 2020. Interestingly, the recovery trend also continuously increased from March 5, 2020. Most importantly, the trend curve for the death cases remains the same during this period. The complete details on the trends of COVID-19 active cases, new cases, recovered cases and death cases until June 7, 2020 in KSA are summarized in Fig. 1. Furthermore, the data from these five major cities Riyadh, Makah, Jeddah, Medina and Dammam were further analysed and the details of the positive cases from between May 1, 2020–Jun 7, 2020 are summarized in Fig. 2. The data clearly pointed that the highest positive cases were reported in Riyadh followed by Makah, Jeddah, Medina and Dammam.

3.2. Effect of weather conditions on COVID-19 positive cases

The detailed relation between the positive COVID-19 cases and weather conditions in KSA was analysed and the complete details are summarized in Fig. 3. The major meteorological parameters such as temperature, humidity, dew point and wind speed were included in the analysis. Fig. 3a shows the curve of daily reported cases versus maximum temperature, whereas the relation of positivity of COVID cases with the average temperature was shown in Fig. 3b. The relation of maximum dew point or average dew point against the daily reported cases of COVID-19 is shown in Fig. 3c and d, respectively. The results showing the relation of daily reported cases against the maximum humidity, average humidity, maximum wind speed, average wind speed, maximum pressure and average pressure are presented in Fig. 3e, f, 3g

and 3h, respectively. A significant correlation was found between the daily reported cases versus temperature, dew point, humidity or wind speed ($p < 0.05$). Whereas, the data on pressure showed no direct relation with the positivity of COVID-19 daily reported cases ($p > 0.05$). The detailed statistical analysis on the correlation between the daily reported COVID-19 cases in Saudi Arabia against the weather conditions are summarized in Table 2.

To study the data in depth, the correlation of daily reported positive cases in Riyadh, Makah, Jeddah, Medina and Dammam versus meteorological parameters such as maximum and average temperature, humidity and wind speed were analysed and the specific details for every city are presented in Fig. 3 and the complete statistical analysis are summarized in Table 3. We found out that on Spearman's correlation of daily cases with meteorological parameters, in Riyadh and Mecca, Medina average temperature and humidity showed a correlation ($p < 0.05$), whereas average wind speed in Riyadh and Medina showed a weak correlation, however in Mecca it revealed a linear correlation coefficient ($p < 0.05$). In Jeddah, Spearman's correlation of daily cases revealed a moderate correlation with temperature whereas weak correlation with humidity and a linear correlation with wind speed whereas in Dammam temperature showed a weak correlation, average humidity revealed a linear correlation however average speed of wind showed a moderate correlation coefficient ($p < 0.05$). We found out that the highest number of cases was reported from Riyadh city whereas data from Dammam revealed a downward trend. In Fig. 4, we presented daily number of positive cases occurring in each city individually in relation to temperature, humidity and wind speed in which we found out that lower average temperature and humidity favours the spread of this infection hence an increase in number of positive cases are reported in these days, we also found that during the days when average speed of wind decrease, the number of positive cases inclined.

4. Discussion

As per our knowledge, no study has been conducted to analyse the impact of weather on the COVID-19 pandemic in the KSA. In this study, we have analysed the association between the COVID-19 infection rates with the weather conditions. The effect of meteorological parameters such as temperature, wind speed, humidity on infectivity of COVID-19 was determined and a correlation with the number of newly infected cases, recovered cases or with the number of deaths was noticed. On Mar 2, 2020, the first case of COVID-19 was reported in KSA from Qateef city, which is located in the eastern province of Saudi Arabia, and the infected patient had a history of travel [18], after which gradually the number of cases started showing an elevated trend. We found the number of newly infected cases in major five cities such as Riyadh, Makah, Medina, Jeddah and Dammam gradually increased during the month of May, however in Riyadh city the cases remarkably increased followed by Mecca and Jeddah city. One of the main factors which can be associated with the rise of cases in these cities is that they are more populated hence human to human transmission of the virus is comparatively easy. During the month of March and April although the new cases were increased at a steady rate and by the end of April, 20,000 new cases were reported however at the beginning of May the number of newly infected cases from COVID-19 sharply increased to about 80,000. Although the preventive measures to thwart the spread of this disease including countrywide lockdown were strictly being implemented during this time, still, a significant increase in the number of infected cases in the month of May was astounding, no doubt that the substantial screening programs carried to identify an infected patient in the general community can be credited to this sudden rise. However, the role of weather cannot be ignored in this situation as it played a significant role in the spread of this disease [22–25]. The average temperature in the month of May in all the cities included in our study was 35 °C, and the maximum temperature reached was 45 °C. Our findings indicate that as the temperature rose, newer infected cases decreased, which is highlighting the fact that

Table 1
Total COVID-19 confirmed cases in the top five cites of Saudi Arabia until June 7, 2020.

City	Population*	Total cumulative cases**	Deaths**
		N. (%)	N. (%)
Riyadh	5,236,901	24,957 (24)	47 (7)
Mecca	1,684,408	17,616 (17)	278 (39)
Jeddah	3,457,794	17,215 (17)	247 (35)
Madina	1,183,205	10,368 (10)	60 (8)
Dammam	914,493	6429 (6)	28 (4)
Saudi Arabia	33,413,660	101,914	712

*The General Authority for Statistics, Saudi Arabia, 2010; **Ministry of Health, Saudi Arabia, 2020.
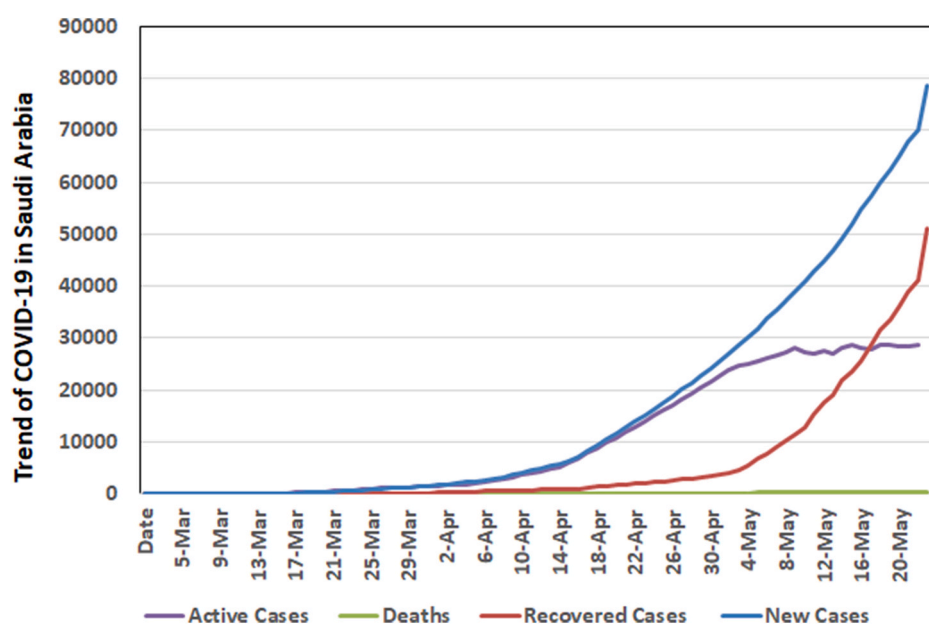
Fig. 1. Trend of COVID-19 in Saudi Arabia: New cases, active cases, recovered cases, and deaths until June 7, 2020.
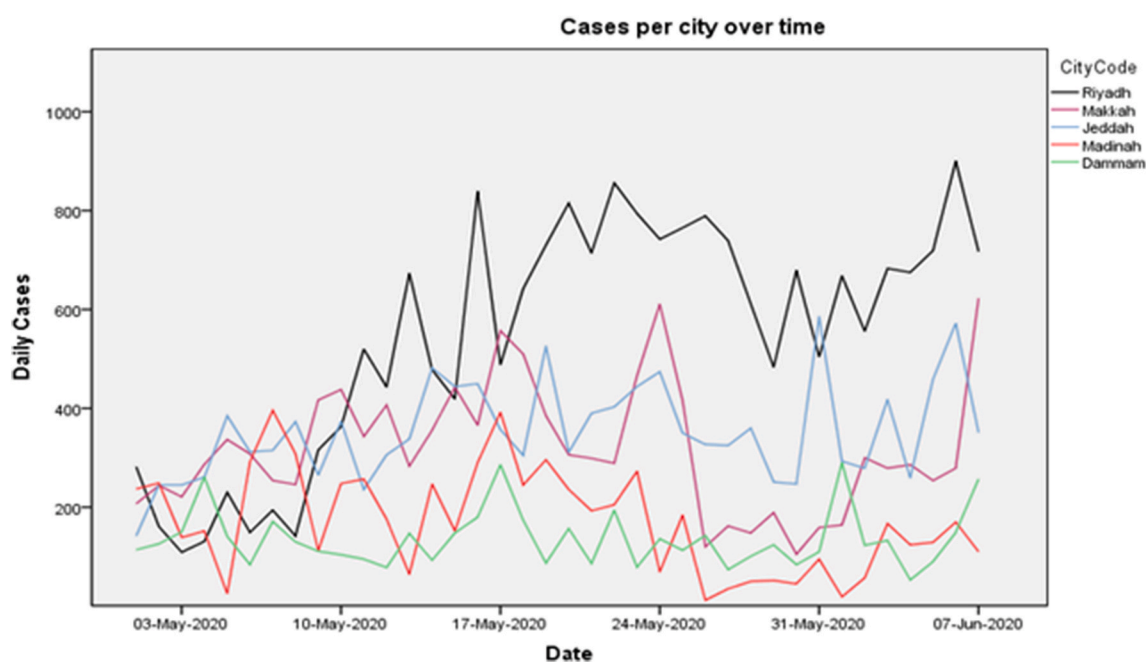

Fig. 2. Positivecases of COVID-19 in major cities Saudi Arabia - Riyadh, Makkah, Jeddah, Madinah and Dammam from between May 1, 2020–Jun 7, 2020.

an increase in environmental temperature might play a role in declining the infection rate. Our statement can also be justified by the fact that the first case of COVID-19 was reported in KSA at the beginning of March 2020, which is almost two months ahead from the first reported case in China [1,2]; the lower temperature in these months might have favoured the spread of corona infection and giving it a form of the pandemic. Similar findings were also reported in Turkey, which fully supported our results [22]. Another study conducted to evaluate the effect of temperature on COVID-19 cases reported that the incidence of newly infected cases elevated when the temperature was less [23], which further supported our findings. Not only have these other studies conducted in Malaysia concluded that temperate plays a negative role for the spread of COVID-19 infection, as they found the infectivity of COVID-19 infection was less in warm weather conditions [24]. Moreover, we

also determined the role of humidity on the COVID-19 spread; our data showed that humidity in the air has a weak correlation with the number of infected cases. In the month of May, KSA reported an increasing trend of newly infected cases when the humidity level gradually was increasing from 60% at the start of the month and reaching an average of 20% in the studied cities. Eastern province comprises fifteen percent of the population of KSA and is bordered by the Arabian Gulf on its eastern side; therefore, the humidity level and dew point in this region is relatively high in comparison to the rest of KSA. In this region, when the average humidity level increased to 40%, the number of positive cases also increased, whereas a decrease in humidity level was associated with fewer new cases. The same association we also have observed in Jeddah city where an increase in humidity was associated with an increase in the number of infected cases. These findings were also supported by
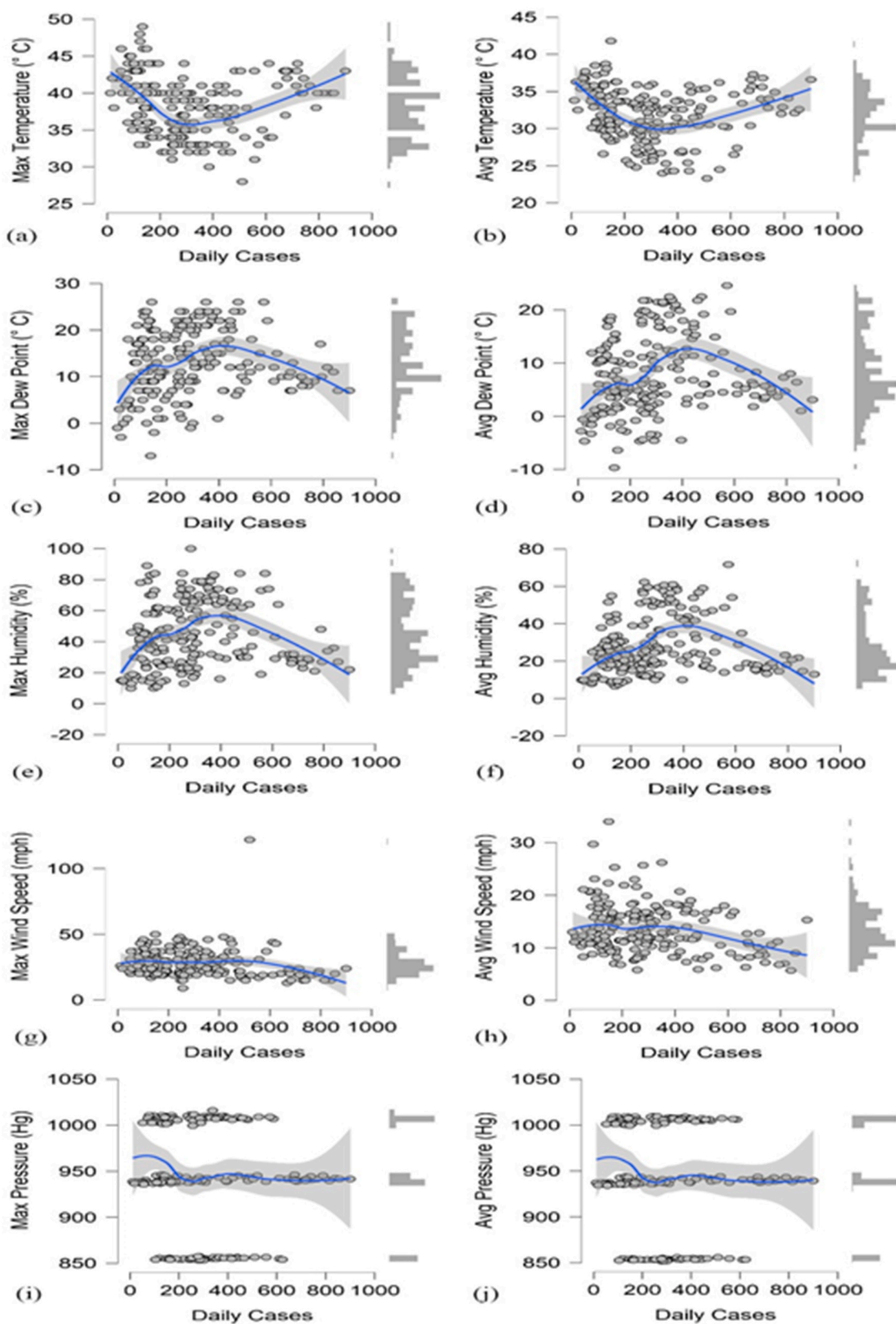
Fig. 3. Combined data of five major cities on the correlation of daily COVID-19 cases with metrological parameters in Saudi Arabia.

Table 2

Spearman's correlation of daily cases with metrological parameters in Saudi Arabia. Combined data from the top five cities of Saudi Arabia.

Metrological parameter	Spearman's rho	p-value	Lower 95% CI	Upper 95% CI
Daily Cases-Max. Temperature (°C)	−0.211**	0.003	−0.343	−0.071
Daily Cases-Avg. temperature (°C)	−0.162*	0.026	−0.297	−0.020
Daily Cases-Max. Dew Point (°C)	0.141	0.053	−0.002	0.277
Daily Cases-Avg. Dew Point (°C)	0.222**	0.002	0.082	0.353
Daily Cases-Max. Humidity (%)	0.132	0.069	−0.010	0.270
Daily Cases-Avg. Humidity (%)	0.194**	0.007	0.053	0.327
Daily Cases-Max. Wind Speed (mph)	−0.257***	<0.001	−0.385	−0.119
Daily Cases-Avg. Wind Speed (mph)	−0.199**	0.006	−0.332	−0.058
Daily Cases-Max. Pressure (Hg)	−0.026	0.725	−0.167	0.117
Daily Cases-Avg. Pressure (Hg)	−0.022	0.758	−0.164	0.120

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3

Spearman's correlation of daily cases with metrological parameters per city in Saudi Arabia.

Metrological parameter	Spearman's rho	p	Lower 95% CI	Upper 95% CI
Riyadh				
Daily Cases-Avg temperature (°C)	0.521***	<0.001	0.241	0.721
Daily Cases-Avg Humidity (%)	−0.406*	0.011	−0.642	−0.099
Daily Cases-Avg Wind Speed (mph)	−0.373*	0.021	−0.619	−0.060
Mecca				
Daily Cases-Max Temperature (°C)	−0.399*	0.013	−0.638	−0.091
Daily Cases-Avg temperature (°C)	−0.470**	0.003	−0.686	−0.177
Daily Cases-Avg Humidity (%)	0.513***	<.001	0.231	0.715
Daily Cases-Avg Wind Speed (mph)	0.022	0.895	−0.300	0.339
Jeddah				
Daily Cases-Max Temperature (°C)	0.445**	0.005	0.147	0.670
Daily Cases-Avg temperature (°C)	0.505**	0.001	0.221	0.710
Daily Cases-Avg Humidity (%)	−0.163	0.329	−0.458	0.166
Daily Cases-Avg Wind Speed (mph)	−0.085	0.611	−0.394	0.241
Madinah				
Daily Cases-Max Temperature (°C)	−0.513***	<.001	−0.715	−0.231
Daily Cases-Avg temperature (°C)	−0.536***	<.001	−0.731	−0.262
Daily Cases-Avg Humidity (%)	0.488**	0.002	0.200	0.699
Daily Cases-Avg Wind Speed (mph)	−0.112	0.503	−0.417	0.215
Dammam				
Daily Cases-Max Temperature (°C)	−0.155	0.354	−0.452	0.174
Daily Cases-Avg temperature (°C)	−0.173	0.298	−0.467	0.155
Daily Cases-Avg Humidity (%)	−0.095	0.571	−0.402	0.232
Daily Cases-Avg Wind Speed (mph)	−0.410*	0.011	−0.645	−0.104

* $p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

other studies, which performed in different regions of the world [25,26]. However, various experimental studies conducted to find the effect of humidity on the survival time of a virus proved that viral inactivation occurs as a result of viral capsids accumulation at the air-water interface of a solution leading to structural damage [27,28].In this study, we found a negative association between speed of wind with the increase in the number of cases it can be attributed to the fact that size of SARS-COV-2 is about 50–200 nm in diameter and so it is transmitted via droplets which can travel to distances of about 4–6 feet after an infected person cough or sneeze before falling to the floor or on other surfaces [29]. An increase in the speed of wind can aid in decreasing the concentration of virus in buildings by contributing to better ventilation. However, according to the World Health Organization (WHO), there is not sufficient evidence that advocates that transmission of SARS-CoV-2 is via the airborne route. Our finding regarding the speed of wind has a role in the transmission of COVID-19 can also be justified by the reason that the cities with a high population such as Riyadh and Mecca have reported more cases despite undertaking strict preventive policies as compared to those regions in which population is less such as Dammam, it might be because the decrease in wind speed in these regions favoured the spread of SARS-COV-2 virus among people living in close vicinity and crowded regions as compared to regions where wind speed is comparatively higher. Air sampling for detection of virus in regions where a number of cases are elevating can give a better understanding of transmission of this virus and can provide a path for authorities to formulate more effective guidelines to control the spread of this virus.

This study has few limitations, firstly, as not all the people who are infected by the SARS-COV-2 virus exhibit symptoms; hence they are not tested for the disease and are not reported. Secondly the incubation period of COVID-19 range from two to fourteen days in which the person remains asymptomatic but can transmit the disease to other people, during this period if that person travels to another city which is not among our study area, his data will be not be reported in the ascendency of the cities which are included in this study. Finally, our findings should be interpreted with caution as using group-level data may result in ecological fallacy.

5. Conclusion

This study determined the impact meteorological factors on the infectivity rate of COVID-19. This study revealed that temperature, humidity, and wind speed can be important factors affecting the COVID-19 infectivity. We determined that the number of COVID-19 cases increased when the temperature and relative humidity were less. Also we found that the number of positive cases increased in those regions where average wind speed was less, particularly in crowded regions where a lesser wind speed was associated with a marked increases in positive cases. As it has been just four months for the occurrence of pandemic in the Saudi Arabia, more studies are required to be conducted on this topic concerning the association of COVID-19 infectivity rate with variation of weather.

Authors' contribution

Mohammad Alkhowailed: Conceptualization, data collection and interpretation and manuscript drafting. Ali Shariq: Data interpretation and manuscript drafting. Fuhaid Alqossayir: Data collection and interpretation and manuscript drafting. Osama A. Alzahrani: Data collection and interpretation and manuscript drafting; Zafar Rasheed: Data interpretation, validation and manuscript drafting. Waleed Al Abdulmonem: Data collection and interpretation and manuscript drafting.
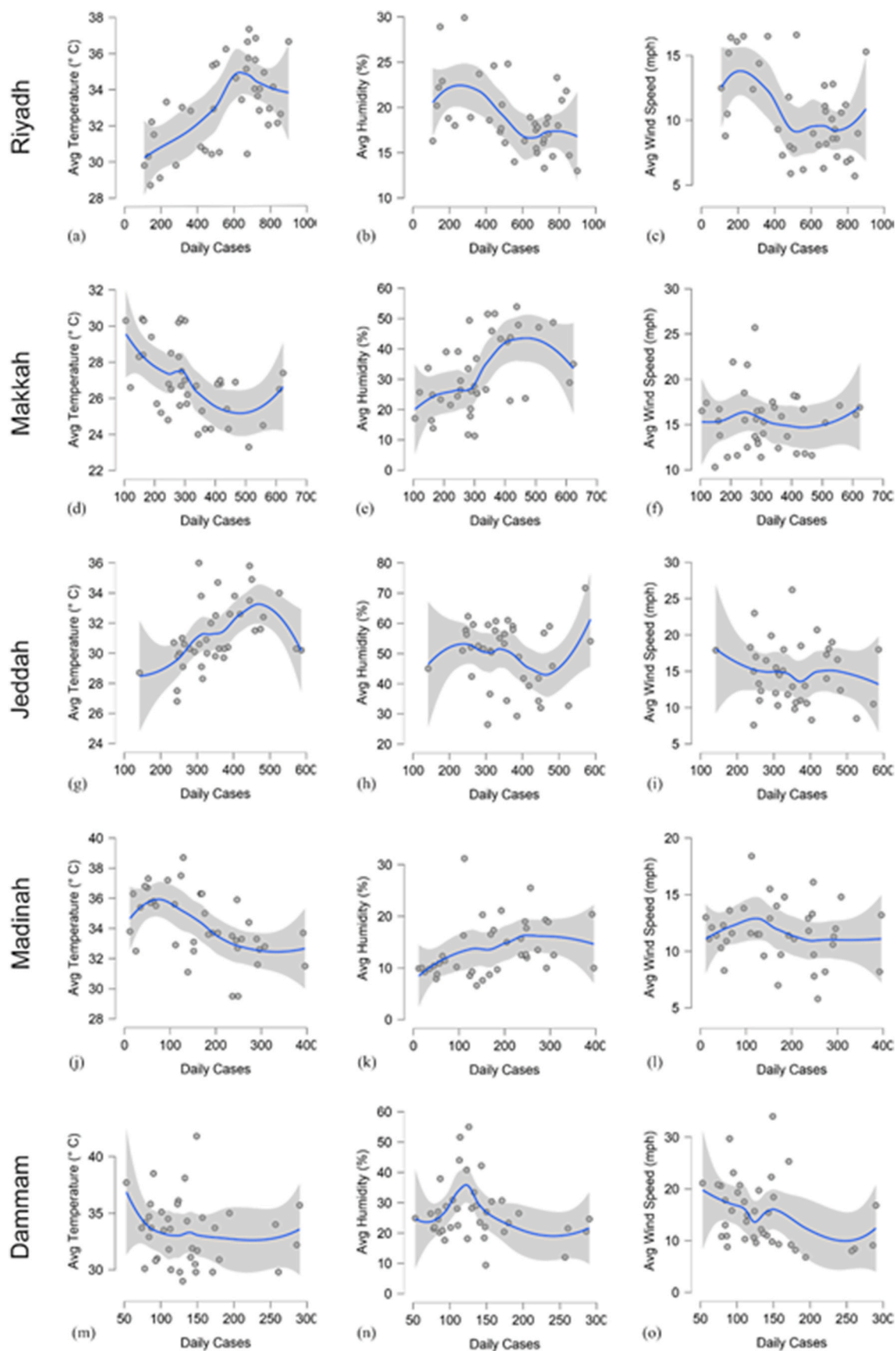
Fig. 4. Correlation of daily COVID-19 cases with metrological parameters per cities in Saudi Arabia.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

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